Examples

Introduction

This appendix offers the following examples:

- Rational Method example problem
- hyetograph example developed from NRCS 24-hour rainfall distributions
- hyetograph example using the Balanced Storm Method
- Muskingham Method
- Standard Step Method
- storm drain design

Rational Method Example Problem

Problem Statement. Both a topographic map and field survey show the area of the drainage basin upstream of a proposed highway culvert, which is found to be 19 hectares (Figure F-1). In terms of soils and surface cover, the existing drainage area is reasonably homogeneous with mostly light woodlands and brush. There appear to be two distinct flow paths converging in the lower area. Local zoning allows light industry in an area adjacent to the highway. The combination of highway improvements and growth in the region make full development of the zoned area attractive and likely within the next few years. The drainage basin is in Hays County. Find the peak discharge for the existing drainage basin and the drainage basin assuming future development in the zoned area. A 10-year design and 100-year check is required for the proposed culvert.

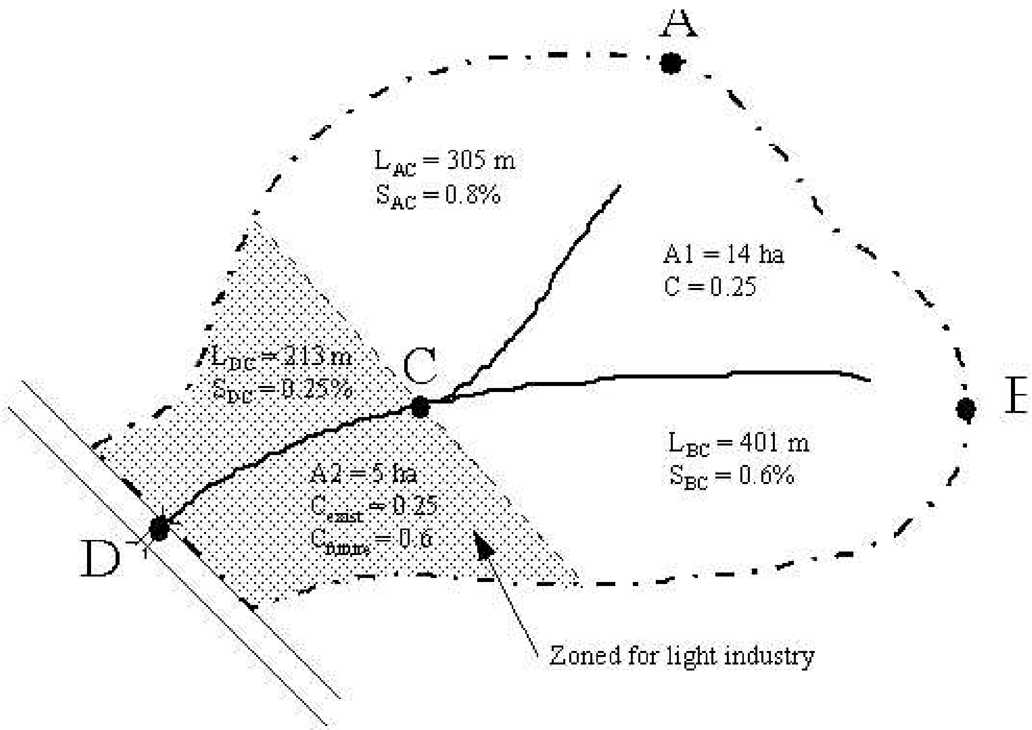

Figure F-1. Drainage Areas for Rational Method Example Problem

Example of Rational Method	
Step	**Action**
Step 1	Determine drainage areas.
Step 2	Determine time of concentration.
Step 3	Ensure limitations of Rational Method have not been exceeded.
Step 4	Select coefficients for 10-year and 100-year flood frequencies for Hays County.
Step 5	Calculate rainfall intensity using Equation 5-5.
Step 6	Calculate composite runoff coefficient.
Step 7	Calculate peak discharges using Equation 5-7 and the table, Runoff Curve Numbers for Urban Areas.

Step 1

Determine drainage areas.

- Total Area = 19 ha.
- Future developed area = 5 ha
- Future undeveloped area = 14 ha

Step 2

Determine time of concentration. With reference to Figure F-1, two likely flow paths are ACD and BCD.

a. For existing conditions, assume path AC is about 50 m of overland flow over pasture and 255 m of grassed waterway. Using Figure 5-4, for a slope of 0.8% and pasture, the velocity, v_{AC1}, is about 0.2 m/s. Similarly, for grassed waterway, the velocity, v_{AC2}, is about 0.42 m/s. The time of travel over length AC is

$$t_{AC} = t_{AC1} + t_{AC2} = \left| \frac{50}{0.2} + \frac{255}{0.42} \right| \Big/ 60 = 14.3 \min$$

b. For existing conditions, the path CD is a grassy channel with an estimated bank-to-bank average velocity, v_{CDe}, of 0.7 m/s. For future conditions, a lined channel is anticipated with an estimated average bank-full velocity, v_{CDf}, of 1 m/s.

- The associated times of travel are

$$t_{CDe} = \frac{213}{0.7 \times 60} = 5.1 \min s$$

and

$$t_{CDf} = \frac{213}{1.0 \times 60} = 3.6 \min s$$

- The time of travel for ACD under existing conditions (t_{ACDe}) is

t_{ACDe} = 14.3 + 5.1 = 19.4 min

- The time of travel for ACD under future conditions (t_{ACDf}) is

t_{ACDf} = 14.3 + 3.6 = 17.9 min

c. Assume path BC is about 50 m of overland flow over pasture and 351 m grassy swale. Using Figure 5-4, for a slope of 0.6% and pasture, the velocity, v_{AC1}, is about 0.19 m/s. Similarly, for grassed waterway , the velocity, v_{AC2}, is about 0.35 m/s.

- The time of travel over length BC is

$$t_{BC} = t_{BC1} + t_{BC2} = \left| \frac{50}{0.19} + \frac{351}{0.35} \right| \Big/ 60 = 21.1 \min$$

- The time of travel for BCD under existing conditions (t_{ACDe}) is

t_{BCDe} = 21.1 + 5.1 = 26.2 min

- The time of travel for BCD under future conditions (t_{ACDf}) is

t_{BCDe} = 21.1 + 3.6 = 24.7 min

$t_{BCDe} > t_{ACDe}$

and

$t_{BCDf} > t_{ACDf}$

d. Under the assumptions of the Rational Method, the longer travel time is taken as the time of concentration. Therefore, for existing conditions the time of concentration, T_e, is 26.2 minutes. For future conditions, the time of concentration, T_f, is 24.7 minutes.

Step 3

Ensure limitations of the Rational Method have not been exceeded.

Because the total drainage area is less than 80 ha, no appreciable storage is indicated, and the watershed shape is not unusual, the Rational Method may be used.

Step 4

Select coefficients for the 10-year and 100-year flood frequencies for Hays County.

Use Hydrology document.

- $e_{10} = 0.776$ $b_{10} = 1981$ $d_{10} = 8.6$
- $e_{100} = 0.755$ $b_{100} = 2642$ $d_{100} = 8.2$

Step 5

Calculate the rainfall intensity using Equation 5-5

a. For existing conditions,

$$I_{10} = \frac{b}{(t_c + d)^e} = \frac{1981}{(26.2 + 8.6)^{0.776}} = 126 \text{ mm/hr}$$

$$I_{100} = \frac{b}{(t_c + d)^e} = \frac{2642}{(26.2 + 8.2)^{0.755}} = 183 \text{ mm/hr}$$

b. For future conditions,

$$I_{10} = \frac{b}{(t_c + d)^e} = \frac{1981}{(24.7 + 8.6)^{0.776}} = 131 \text{ mm/hr}$$

$$I_{100} = \frac{b}{(t_c + d)^e} = \frac{2642}{(24.7 + 8.2)^{0.755}} = 189 \text{ mm/hr}$$

Step 6

Calculate composite runoff coefficient.

a. For existing conditions, the area is homogeneous with C = 0.25.

b. For future conditions,

$$C = \frac{C_1 A_1 + C_2 A_2}{A_1 + A_2} = \frac{0.25(14) + 0.6(5)}{14 + 5} = 0.34$$

Step 7

Calculate peak discharges using Equation 5-5 ***and*** the "Runoff Curve Numbers for Urban Areas."

a. For 10 year, $C_f = 1.0$. For 100 year, $C_f = 1.25$.

b. For existing conditions,

$$Q_{10} = \frac{CIA}{360} = (0.25)(126)(19) / 360 = 1.66 \text{ m}^3 / \text{s}$$

$$Q_{100} = \frac{CC_f IA}{360} = (0.25)(1.25)(183)(19) / 360 = 3.02 \text{ m}^3 / \text{s}$$

c. For future conditions,

$$Q_{10} = \frac{CIA}{360} = (0.34)(131)(19) / 360 = 2.35 \text{ m}^3 / \text{s}$$

$$Q_{100} = \frac{CC_f IA}{360} = (0.34)(1.25)(189)(19) / 360 = 4.24 \text{ m}^3 / \text{s}$$

Hyetograph Example Developed from NRCS 24-Hour Rainfall Distributions

The following is an example of a rainfall hyetograph for a 25-year, 24-hour storm in Harris County. For demonstration only, a one-hour time increment is used.

Total precipitation (from Hydrology) = 244 mm

Distribution type (from Figure 5-8) = III

The "Rainfall Groups for Antecedent Soil Moisture Conditions During Growing and Dormant Seasons" presents the calculations. Figure 5-11 shows the resulting hyetograph.

For time = 1 hour,

1. The cumulative fraction is determined by interpolation of the Runoff Curve Numbers for Arid and Semi Arid Rangelands :
   $P_1/P_{24} = 0 + (0.02–0) \times (1–0)/(2-0) = 0.01$.
2. The cumulative rainfall is the product of the cumulative fraction and the total 24-hour rainfall: $P_1 = 0.01 \times 244 = 2.44$ mm.
3. The incremental rainfall is the difference between the current and preceding cumulative rainfall values: 2.44–0 = 2.44 mm.

Repeating the procedure for each time period yields the complete hyetograph ordinates.

Hyetograph Example Using the Balanced Storm Method

The following represents the development of a five-year, three-hour duration rainfall hyetograph for Travis County. The rainfall intensity coefficients are e = 0.78, b = 1753, d = 8.6 (Appendix B). The duration is 3 hours = 180 minutes. Using 15 minute intervals, the total number of intervals is 180/15 = 12. For a duration of 15 minutes,

- the intensity is $1753/(15 + 8.6)^{0.78} = 148.91$ mm/hour (using Equation 5-5 where the duration replaces time of concentration)
- the cumulative depth is 148.91 × 15 (min) / 60 (min per hour) = 37.23 mm
- the incremental depth is 37.23–0 = 37.23 mm

Calculation of the values for each duration up to 180 minutes is similar. The "Example of Balanced Storm" table tabulates the calculations. The highest incremental rainfall (always at the shortest duration) is 37.23 mm. This is assigned the central time block of 75–90 minutes. The next highest, 13.50, is assigned to the 90–105 minute time block, which is after the central block. The next highest increment is 8.17 and is assigned to the 60–75 minute time block which immediately precedes the central time block. This distribution continues alternating between next available time blocks from the central block. Figure F-2 shows the resulting hyetograph.

Example of Balanced Storm Tabulation					
Duration (min)	**Intensity (mm/hr)**	**Cum. Depth (mm)**	**Incr. Depth (mm)**	**Time Block (mm)**	**Rainfall (mm)**
15	148.91	37.23	37.23	0-- 15	2.12
30	101.45	50.72	13.50	15-30	2.56
45	78.53	58.90	8.17	30-45	3.27
60	64.78	64.78	5.88	45-60	4.62
75	55.52	69.40	4.62	60-75	8.17
90	48.82	73.22	3.82	75-90	37.23
105	43.71	76.49	3.27	90-105	13.50
120	39.68	79.36	2.87	105-120	5.88
135	36.41	81.92	2.56	120-135	3.82
150	33.69	84.23	2.31	135-150	2.87
165	31.40	86.35	2.12	150-165	2.31
180	29.43	88.30	1.95	165-180	1.95

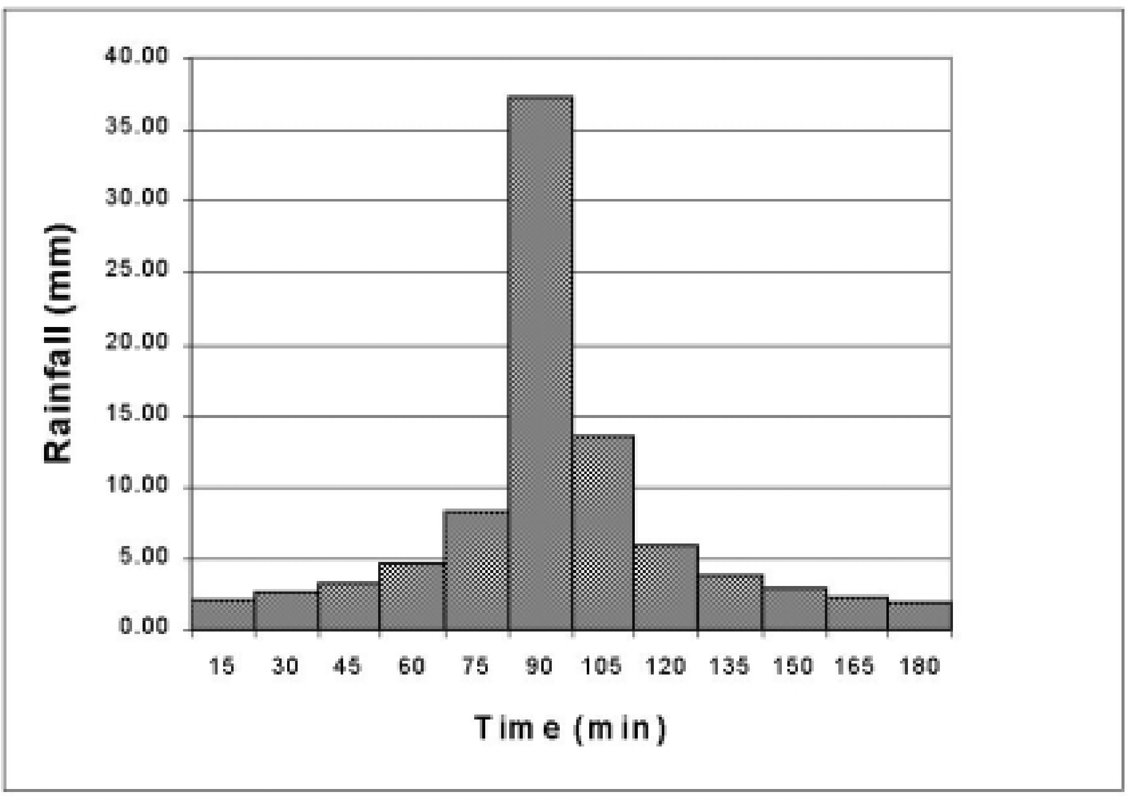

Figure F-2. Example of Hyetograph Using Balanced Storm Method

Muskingum Method

The example shown in the "Channel Routing Using the Muskingum Method" table shows a triangular hydrograph routed through three 1000 meter reaches of channel. The outflow hydrograph for each reach is used as the inflow for the next. The channel has a ‘K’ of 0.278 hours (1000 seconds) and an × of 0.2.

Using Equations 5-30, 5-31, and 5-32 with a time increment of 1000 sec,

$$C_1 = \frac{1000 - 2(1000)(0.2)}{2(1000)(1-0.2)+1000} = 0.23077$$

$$C_2 = \frac{1000 + 2(1000)(0.2)}{2(1000)(1-0.2)+1000} = 0.53846$$

$$C_3 = \frac{2(1000)(1-0.2) - 1000}{2(1000)(1-0.2)+1000} = 0.23077$$

Check: C1 + C2 + C3 = 0.23077 + 0.23077 + 0.53846 = 1

For time step two, (t = 2), first reach:

$$O_2 = (0.23077)(200) + (0.53846)(0) + (0.23077)(0) = 46.15 \text{ m}^3/\text{s}$$

For time step 3 (t = 3):

$$O_3 = (0.23077)(400) + (0.53846)(200) + (0.23077)(46.15) = 210.65 \text{ m}^3/\text{s}$$

Repeating the process until the outflow hydrograph is complete. The outflow hydrograph from reach one becomes the inflow hydrograph for reach 2, and the process is repeated for reaches 2 and 3. Figure F-3 shows a plot of the hydrographs. Since the outflow hydrograph represents a displacement in distance as well as time, the peak outflow does not coincide with the receding limb of the inflow hydrograph.

Channel Routing Using the Muskingum Method					
Time step	**Time (s)**	**Inflow (m^8/s)**	**Outflow (m^8/s)**		
			Reach 1	**Reach 2**	**Reach 3**
1	0	0	0	0	0
2	1000	200	46.15	10.65	2.46
3	2000	400	210.65	75.92	23.82
4	3000	300	333.23	207.85	94.34
5	4000	200	284.59	293.07	201.32
6	5000	100	196.44	266.21	265.70
7	6000		99.18	190.10	248.52
8	7000		22.89	102.55	183.38
9	8000		5.28	37.21	106.13
10	9000		1.22	11.71	47.23
11	10000		0.28	3.472	18.00
12	11000		0.06	0.96	6.22
13	12000		0.01	0.26	2.01
14	13000		0.00	0.07	0.62
15	14000		0.00	0.02	0.18
16	15000		0.00	0.00	0.05
17	16000		0.00	0.00	0.02
18	17000		0.00	0.00	0.00

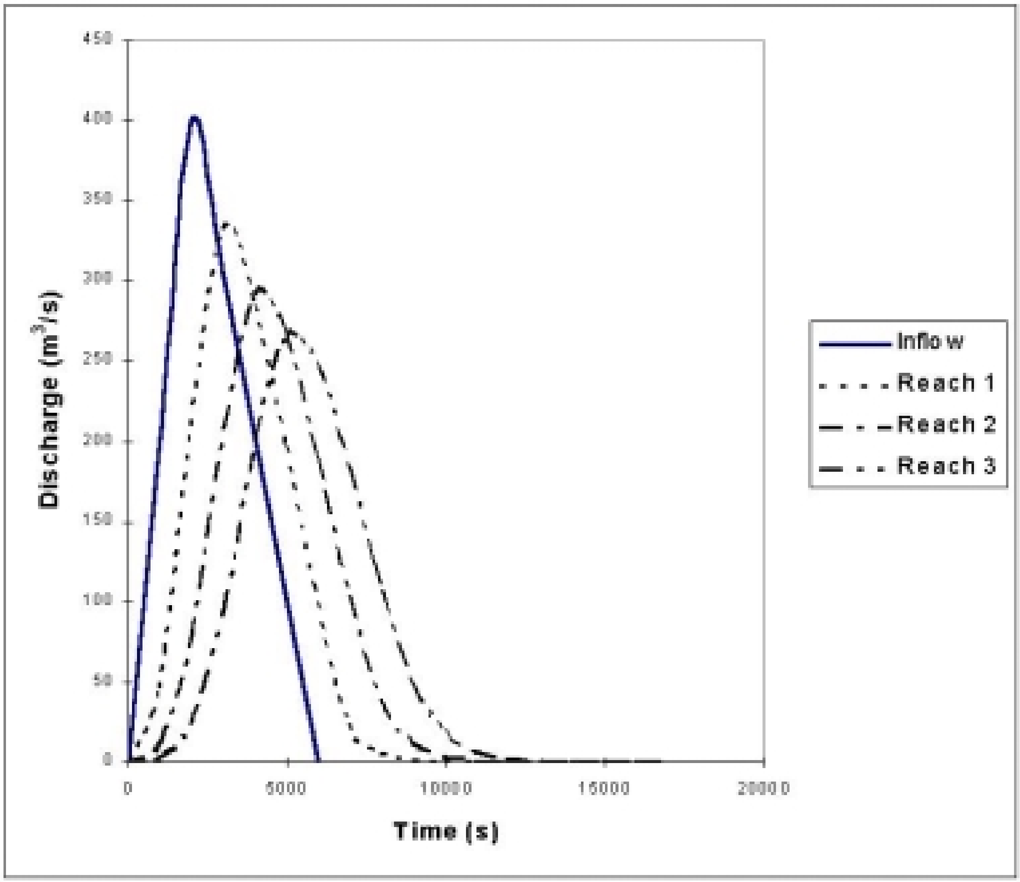

Figure F-3. Plot of a Triangular Hydrograph Routed Through Three Segments of Channel

Standard Step Method

Four cross sections along a reach are shown in Figures 7-17, 7-18, 7-19, 7-20. Each cross section is separated by 152.4 m, and is subdivided according to geometry and roughness. The calculations shown in WS Elevation of 23.5 m represent one set of water-surface calculations. An explanation of WS Elevation of 23.5 m follows the calculations. The calculations represent the results of iterations at each section.

Column 1. This column contains the cross section identification name.

Column 2. This column contains the stream cross section station number.

Column 3. The assumed water surface elevation must agree with the resulting computed water surface elevation within ± 0.05 meters (or some other allowable tolerance) for trial calculations to be successful.

Column 4. This is the stage-discharge (rating) curve value for the first section; thereafter, it is the value calculated by adding ΔWS (Column 21) to the computed water surface elevation for the previous cross section.

Column 5. A is the cross-sectional area. If the section is complex and has been subdivided into several parts (e.g., left overbank, channel, and right overbank), then use one line of the form for each subsection and add to get the total area of cross section (A_t).

Column 6. This column contains the wetted perimeter. If the section is subdivided, then use one line for each subsection wetted perimeter.

Column 7. R is the hydraulic radius. Use the same procedure as for Column 5 if the section is complex, but do not add subsection values.

Column 8. n is Manning's coefficient of channel roughness.

Column 9. K is the conveyance and is determined with Equation 6-4. This column contains the total conveyance for the cross section. If the cross section is complex, add subsection K values to get the total conveyance (K_t).

Column 10. K_{ave}, the average conveyance for the reach is computed with Equation F-1:

$$K_{ave} = \frac{1}{2}\left(K_{ds} + K_{us}\right)$$

Equation F-1

Column 11. This column contains the friction slope at the current section and is computed using Equation 6.7–8.

$$S_f = \left|\frac{Q}{K}\right|^2$$

Equation F-2

Column 12. The average friction slope is determined using Equation F-3.

$$S_{f\,ave} = \left|\frac{Q}{K_{ave}}\right|^2$$

Equation F-3

Column 13. L is the distance between cross-sections.

Column 14. The energy loss due to friction (h_f) through the reach is calculated using Equation F-4.

$$h_f = S_{ave}\, L$$

Equation F-4

Column 15. This column contains part of the expression relating distributed flow velocities to an average value (see Column 16). If the section is complex, calculate one of these values for each subsection, and add all subsection values to get a total. If one subsection is used, you do not need Column 15, and the kinetic energy coefficient (Column 16) equals 1.0.

Column 16. The kinetic energy coefficient (α) is calculated with Equation 6-10 .

Column 17. The average velocity (V) for the cross section is calculated with the continuity equation (Equation 6-1).

Column 18. This column contains the average velocity head, corrected for flow distribution.

Column 19. This column contains the difference between the downstream and upstream velocity heads. A positive value indicates velocity is increasing; therefore, use a contraction coefficient to account for "other losses." A negative value indicates the expansion coefficient should be used in calculating "other losses."

Column 20. Calculate the "other losses" by multiplying either the expansion coefficient (K_e) or contraction coefficient (K_c) by the absolute value of Column 18. That is, for expansion, the change in velocity head will be negative, but the head loss must be positive. ΔWS is the change in water surface elevation from the previous cross section. It is the algebraic sum of Columns 14, 19 and 20.

Storm Drain Design

Problem Statement

Given: The working schematic, Figure F-4, shows the layout of the roadway and cross streets to be drained. At the node indicated as A8 on the schematic, an outflow from a small storm drain system within the indicated shopping mall is accepted into the department's system. The storm drain system will outfall into a channel which is directly downstream of a culvert as indicated. The culvert accommodates flow from a 906.5 hectare watershed.

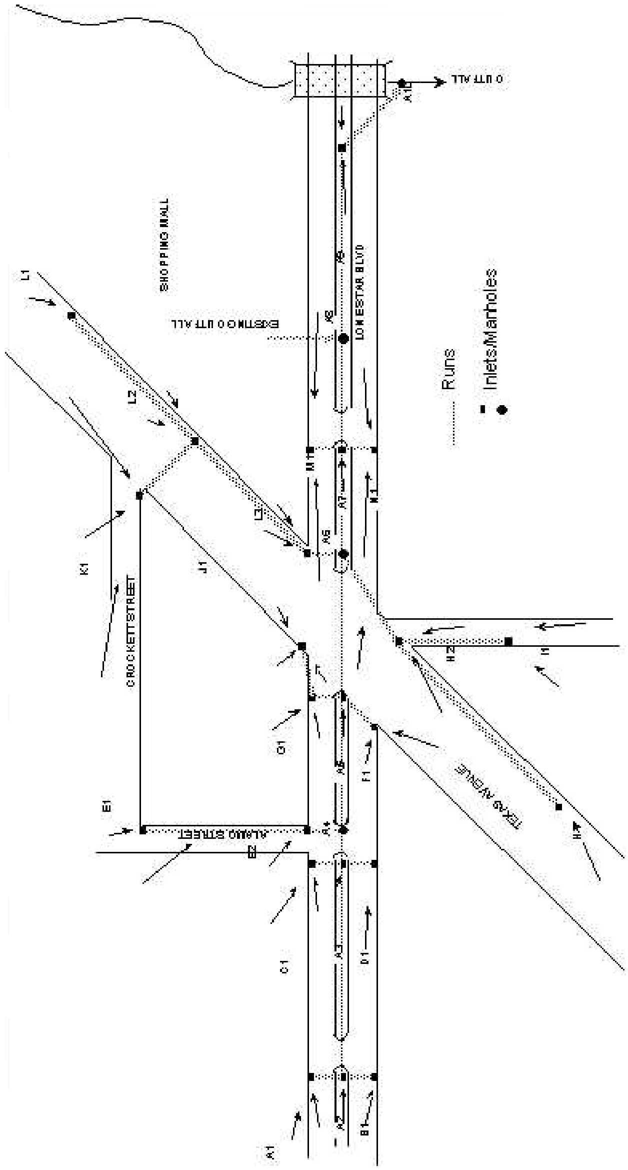

Figure F-4. Layout of Drainage Areas and Inlets

The hydrology and inlet data for this example are given in "Hydrology and Inlet Information table." This table includes the following for each drainage area:

- area
- time of concentration
- gutter slope
- reciprocal of the cross slope

Hydrology and Inlet Information

Identification	Type	Area (ha)	C	Actual Time (min)	$1/S_x$ (m/m)	Slope (m/m)
A1	Curb	0.69 0.10	0.55 0.85	7.5	24	0.0050
A2	SGrate	0.06	0.70	2.0	32	
B1	Slot	0.11	0.85	3.2	24	0.0050
C1	Curb	0.78 0.14	0.50 0.85	14.5	32	0.0060
A3	SGrate	0.10	0.70	2.0	32	
D1	Slot	0.14	0.85	4.1	32	0.0060
E1	Slot	0.22	0.50	5.0	48	0.0065
E2	Curb	0.42 0.11	0.55 0.85	13.5	48	0.0060
A4	Junc					
G1	Curb	0.41 0.11	0.50 0.85	9.0	32	0.0060
A5	SGrate	0.05	0.70	2.0	32	
F1	Slot	0.09	0.85	3.6	32	0.0060
H1	Curb	0.08 0.06	0.55 0.85	6.0	48	0.0030
H2	Curb	0.12 0.22	0.55 0.85	6.5	48	0.0050

(continued): Hydrology and Inlet Information						
Identification	**Type**	**Area (ha)**	**C**	**Actual Time (min)**	**$1/S_x$ (m/m)**	**Slope (m/m)**
I1	Slot	0.32 0.07	0.55 0.85	8.0	48	0.0030
K1	Grate	0.66 0.13	0.40 0.85	15.0	48	0.0040
J1	Scurb	0.43 0.21	0.60 0.85	8.8	32	
L1	Grate	0.30 0.07	0.55 0.85	17.7	48	0.0040
L2	Grate	0.24	0.85	3.6	48	0.0040
L3	Grate	0.17	0.85	3.0	48	0.0040
A6	Junc					
M1	SCurb	0.33	0.85	4.2	32	
A7	SGrate	0.04	0.70	2.0	32	
N1	SCurb	0.41	0.85	7.0	32	
Offsite		0.18 1.49	0.70 0.85	11.6		
A8	Junc					
A9	Sgrate	0.12	0.70	3.4	32	
A10	Outfall					

The "Conduit Information" table presents conduit design information such as soffit elevations and pipe lengths. The "General Given Information" table contains general information, including

- rainfall intensity factors
- allowable ponded widths and
- inlet requirements

Conduit Information

Identifications		Length (m)	U/S Soffit Elev. (m)
U/S	D/S		
A1	A2	20	256.760
B1	A2	20	256.730
A2	A3	100	256.670
C1	A3	20	256.260
D1	A3	20	256.270
A3	A4	20	256.200
E1	E2	90	256.600
E2	A4	20	256.150
A4	A5	75	256.090
G1	A5	20	255.810
F1	A5	25	255.830
A5	A6	75	255.730
J1	G1	25	255.940
H1	H2	125	255.880
I1	H2	60	255.810
H2	A6	57	255.560
L1	L2	95	256.320
K1	L2	55	256.070
L2	L3	86	255.850
L3	A6	20	255.570
A6	A7	56	255.490
M1	A7	20	255.300
N1	A7	18	255.240
A7	A8	60	255.220
A8	A9	104	254.880
A9	A10	40	254.270

General Given Information

Design Frequency	5 years (20% chance of exceedance)
Rainfall intensity factors	e = 0.78, b = 1422 mm, d = 8.2
Curb height	0.15 m
Minimum time of concentration	10 minutes
Minimum curb inlet length	1.5 m
Minimum slotted drain inlet length	6 m
Standard grate inlets	Parallel bars w/transverse rods, W = 0.5 m and L = 1 m
Grate inlets on sag in median	0.5 m x 0.5 m square inlets, bar area = 25% of grate area, allowable ponded depth = 0.6 m
Gutter depression for curb inlets	75 mm
Allowable ponded width	3.6 m on Lone Star Blvd. and 4.5 m on Texas Ave.
Curb inlets on sag	slope = 0.0050 m/m, and 50% of discharge on each side of inlet
Outfall tailwater elevation (2 yr)	254.360 m

Required: Design a storm drain system to accommodate the design discharge.

Discussion: The following example represents a single iteration of the design process. It is one of a series of iterations that would require revision, re-analysis, and optimization until a technically acceptable and economical design is accomplished.

In a production design, all design parameters and criteria must be met. The illustration of the hydraulic grade line is for demonstration only. Typically, the hydraulic grade line is developed as a last design step after the system has been optimized. The next subsections offer initial design process components and a design iteration procedure.

Initial Design Process Components

The initial design process consists basically of the following three components:

- hydrology
- inlet design and
- conduit design.

These components will be addressed individually. However, it is important to understand that all three components must function together simultaneously. You must evaluate the hydrology aspects with respect to both inlet design and conduit design.

Design Iteration Procedure

The following steps illustrate the activities in a single design iteration.

Design Iteration Procedure	
Step	**Action**
Step 1	Prepare a system plan.
Step 2	Base initial runoff computations on Rational Method and tabulate them in "Conduit Information" table.
Step 3	Locate inlets based on logic and hydraulic demand, and configure the conduit system.

Step 1

Prepare a system plan.

Prepare a system plan as discussed in Section 2, System Planning. Effectively, the example problem is identified as delineated in the problem statement. Ensure there are no “dead” spots where the runoff has no outlet. Establish the general location of inlets, the laterals, and the trunk lines. You must coordinate the logical location of the various system components with the component locations necessary to satisfy hydraulic demand. In subsequent design iterations, you may change any or all parts of the system configuration as necessary.

a. Establish the design parameters and criteria.

b. Select materials and shapes to be used.

c. Assign the design frequency.

d. Identify utility intersections with respect to
   - location
   - type
   - owner and probable disposition.

e. Identify detention facilities.

Step 2

Base initial runoff computations on the Rational Method, and tabulate them in "Conduit Information" ***table.*** The first four columns of this tabulation are self-explanatory. The total CA, as shown in the fifth column, is computed by multiplying each incremental area by its corresponding coefficient of runoff and summing these incremental products. As an example, the total CA for drainage area A1 is computed as follows:

Type	Hectares		C		CA
Paved	0.10	x	0.85	=	0.085
Residential	0.69	x	0.55	=	0.380
TOTALS	0.79				0.465

Summary of Hydrologic Computations

Identification	Type	Area (ha)	C	CA (ha)	Actual Time (min)	t_c (min)	I (mm/hr)	Q (m^3/s)
A1	Curb	0.69 0.10	0.55 0.85	0.465	7.5	10.0	147.93	0.191
A2	SGrate	0.06	0.70	0.042	2.0	10.0	147.93	0.017
B1	Slot	0.11	0.85	0.094	3.2	10.0	147.93	0.038
C1	Curb	0.78 0.14	0.50 0.85	0.509	14.5	14.5	124.51	0.176
A3	SGrate	0.10	0.70	0.070	2.0	10.0	147.93	0.029
D1	Slot	0.14	0.85	0.119	4.1	10.0	147.93	0.049
E1	Slot	0.22	0.50	0.110	5.0	10.0	147.93	0.045
E2	Curb	0.42 0.11	0.55 0.85	0.325	13.5	13.5	128.96	0.116
A4	Junc	0.00	0.00					
G1	Curb	0.41 0.11	0.50 0.85	0.299	9.0	10.0	147.93	0.123
A5	SGrate	0.05	0.70	0.035	2.0	10.0	147.93	0.014
F1	Slot	0.09	0.85	0.077	3.6	10.0	147.93	0.031
H1	Curb	0.08 0.06	0.55 0.85	0.095	6.0	10.0	147.93	0.039
H2	Curb	0.12 0.22	0.55 0.85	0.253	6.5	10.0	147.93	0.104
I1	Slot	0.32 0.07	0.55 0.85	0.236	8.0	10.0	147.93	0.097

(continued): Summary of Hydrologic Computations								
Identification	**Type**	**Area (ha)**	**C**	**CA (ha)**	**Actual Time (min)**	**t_c (min)**	**I (mm/hr)**	**Q (m^3/s)**
K1	Grate	0.66 0.13	0.40 0.85	0.375	15.0	15.0	122.41	0.127
J1	SCurb	0.43 0.21	0.60 0.85	0.437	8.8	10.0	147.93	0.180
L1	Grate	0.30 0.07	0.55 0.85	0.225	17.7	17.7	112.34	0.070
L2	Grate	0.24	0.85	0.204	3.6	10.0	147.93	0.084
L3	Grate	0.17	0.85	0.145	3.0	10.0	147.93	0.059
A6	Junc	0.00	0.00					
M1	SCurb	0.33	0.85	0.281	4.2	10.0	147.93	0.115
A7	SGrate	0.04	0.70	0.028	2.0	10.0	147.93	0.012
N1	SCurb	0.41	0.85	0.349	7.0	10.0	147.93	0.143
Offsite		0.18 1.49	0.70 0.85	1.393	11.6	11.6	138.52	0.536
A8	Junc	0.00	0.00					
A9	SGrate	0.12	0.70	0.084	3.4	10.0	147.93	0.035
A10	Outfall	0.00	0.00					

a. In the "Summary of Hydrologic Computations" table, note that the operating time of concentration has a minimum value of 10 minutes (according to department practice). However, it is necessary to account for the smaller time of concentration; therefore, the actual time of concentration (minimum notwithstanding) is also tabulated.

b. The rainfall intensity (I) is based on Equation F-5, where e = 0.78, b = 1422, and d = 8.2. For drainage area A1, the time of concentration is only 7.5 minutes. Therefore, using 10 minutes as a basis, the rainfall intensity is calculated as 147.9 mm/hr.

$$I_f = \frac{b}{(t_c + d)^e}$$

Equation F-5

where:

I_f=rainfall intensity for frequency (mm/hr)

t_c=time of concentration (min)

e, b, d= empirical factors which are tabulated for each county in Texas for frequencies of 2, 5, 10, 25, 50, and 100 years in Appendix B.

c. The peak discharge (Q) is determined by multiplying CA by I and 0.00278 (Equation F-6).

$$Q = \frac{C\,I\,A}{360}$$

Equation F-6
where:

Q	=peak discharge (m^3/s)
C	=runoff coefficient
I	=rainfall intensity associated with a specific frequency (mm/hr)
A	=area of the watershed (ha)

d. For watershed A1, Q is 0.191 m^3/s.

Step 3

Locate the inlets based on logic and hydraulic demand, and configure the conduit system.

a. Locate the inlets based on logic and hydraulic demand as outlined in Section 5, Storm Drain Inlets.

b. Finally, after locating the inlets (establishing the nodes for the storm drain system), you can configure the conduit system.

Tables F-7 to F-13 show the suggested tabular format for calculations in the design of the inlet system in this example. Since the design process is iterative, requiring adjustments and re-analysis until the design is optimized, the examples shown are only a "snapshot" (or one iteration) during the design process.

Inlets On-Grade Explanation

$$C = \frac{\sum_{n=1}^{m} C_n A_n}{\sum_{n=1}^{m} A_n}$$

Equation F-7

where:

C=weighted runoff coefficient
n=nth subarea
m=number of subareas
C_n=runoff coefficient for nth subarea
A_n=nth subarea size (ha)

On Grade Inlet Calculations

On-Grade Inlets																
1 ID	**2 Type**	**3 Area ha**	**4 Wtd C**	**5 CA ha**	**6 Actual t_c min**	**7 Inlet Time min**	**8 Intensity mm/hr**	**9 Q m^3/s**	**10 CO m^3/s**	**11 Total Q m^3/s**	**12 $1/S_x$ m/m**	**13 Slope m/m**	**14 y m**	**15 T m**	**16 a m**	**17 E**
A1	Curb	0.79	0.59	0.46	7.5	10.0	147.93	0.191	0.000	0.191	24	0.0050	0.132	3.16	0.075	
C1	Curb	0.92	0.55	0.51	14.5	14.5	124.51	0.176	0.010	0.186	32	0.0060	0.113	3.62	0.075	
E1	Slot	0.22	0.50	0.11	5.0	10.0	147.93	0.045	0.000	0.045	48	0.0065	0.056	2.70		0.31
E2	Curb	0.53	0.61	0.32	13.5	13.5	128.96	0.116	0.002	0.118	48	0.0060	0.082	3.93	0.075	
G1	Curb	0.52	0.57	0.30	9.0	10.0	147.93	0.123	0.005	0.128	32	0.0060	0.098	3.14	0.075	
K1	Grate	0.79	0.47	0.37	15.0	15.0	122.41	0.127	0.000	0.127	48	0.0040	0.091	4.36		
L1	Grate	0.37	0.61	0.22	17.7	17.7	112.34	0.070	0.000	0.070	48	0.0040	0.073	3.49		
L2	Grate	0.24	0.85	0.20	3.6	10.0	147.93	0.084	0.027	0.111	48	0.0040	0.086	4.15		
L3	Grate	0.17	0.85	0.14	3.0	10.0	147.93	0.059	0.050	0.110	48	0.0040	0.086	4.13		
B1	Slot	0.11	0.85	0.09	3.2	10.0	147.93	0.038	0.000	0.038	24	0.0050	0.072	1.73		0.32
D1	Slot	0.14	0.85	0.12	4.1	10.0	147.93	0.049	0.000	0.049	32	0.0060	0.069	2.19		0.33
F1	Slot	0.09	0.85	0.08	3.6	10.0	147.93	0.031	0.000	0.031	32	0.0060	0.058	1.86		0.33
I1	Slot	0.39	0.60	0.24	8.0	10.0	147.93	0.097	0.000	0.097	48	0.0030	0.087	4.16		0.31
H1	Curb	0.14	0.68	0.10	6.0	10.0	147.93	0.039	0.000	0.039	48	0.0030	0.062	2.96	0.075	
H2	Curb	0.34	0.74	0.25	6.5	10.0	147.93	0.104	0.009	0.113	48	0.0050	0.083	3.99	0.075	

On Grade Inlet Calculations (part 2)

On-Grade Inlets (Continued)											
ID	**18 W m**	**19 L grate m**	**20 L_r curb m**	**21 L_r slot m**	**22 L_a m**	**23 L_a/L_r**	**24 a/W**	**25 C.O. m^3/s**	**26 C.O. to**	**27 Qi m^3/s**	**28 Remarks**
A1	0.5		3.70		3	0.81	0.57	0.010	C1	0.181	see the Correction Factor K2 for Angle of Flow Attack table for CURB inlet calculations
C1	0.5		4.18		6	1.43	0.66	0.000	E2	0.186	see the Correction Factor K2 for Angle of Flow Attack table for CURB inlet calculations
E1				7.33	6	0.82		0.002	E2	0.043	
E2	0.5		3.65		3	0.82	0.92	0.005	G1	0.113	see the Correction Factor K2 for Angle of Flow Attack table for CURB inlet calculations
G1	0.5		3.40		3	0.88	0.76	0.003	J1	0.125	see the Correction Factor K2 for Angle of Flow Attack table CURB inlet calculations
K1	0.5	1						0.060	J1	0.068	C.O. to SAG, see the Correction Factor K3 for Bed Condition table for GRATE calcs.
L1	0.5	1						0.027	L2	0.043	see the Correction Factor K3 for Bed Condition table for GRATE calculations
L2	0.5	1						0.050	L3	0.061	see the Correction Factor K3 for Bed Condition table GRATE calculations
L3	0.5	1						0.049	M1	0.060	C.O. to SAG, see the Correction Factor K3 for Bed Condition table for GRATE calcs.
B1				3.30	6	1.82		0.000	D1	0.038	
D1				4.72	6	1.27		0.000	F1	0.049	
F1				3.88	6	1.55		0.000	H2	0.031	
I1				8.06	6	0.74		0.008	H2	0.089	

H1	0.5		1.65		1.5	0.91	1.22	0.001	H2	0.039	see the Correction Factor K2 for Angle of Flow Attack table for CURB inlet calculations
H2	0.5		3.40		4.5	1.32	0.90	0.000	N1	0.113	see the Correction Factor K2 for Angle of Flow Attack table for CURB inlet calculations

The following procedure refers to the format of the "On Grade Inlet Calculations" table, part 1 and part 2.

Column 1. Identify all inlets with a unique name. Here is a suggested system of alphanumeric characters that relates to each storm drain line. This system is compatible with the system of identification used in WinStorm for storm drain system design and analysis. The first inlet is identified as A1. It is useful to identify the longest conduit line A. Nodes on that line may be numbered in order from either direction. For example, in WinStorm, the first inlet would carry an identification of A1.

Column 2. This column indicates the type of inlet used at each location. For example, at node A1, a curb opening inlet is used (described here as “Curb”).

Column 3. This column shows the drainage area size in hectares.

Column 4. Here is the weighted runoff coefficient for the identified drainage area. The weighted runoff coefficient is calculated using Equation F-7.

Column 5. This is the product of the weighted runoff coefficient and the drainage area. This value is the total CA for the watershed (also tabulated in the Conduit Information table).

Column 6. This column shows the actual time of concentration for the drainage area.

Column 7. Here is the time of concentration used for the derivation of the rainfall intensity. Use the actual time of concentration or 10 minutes, whichever is greater.

Column 8. Rainfall intensity for frequency, f, is based on the intensity formula (Equation F-5).

Column 9. This is the peak discharge for the subject drainage area, calculated using the Rational Equation ($Q = C\ I\ A/360$, or $Q = I\ \Sigma(CA)\ /360$).

Column 10. The carry-over in this column is the rate of discharge which has passed by the last upstream (gutter) inlet. Always accommodate the rate of carry-over from any inlet. Carry-over that is not accommodated can be very troublesome and can cause severe traffic interruption problems. Any carry-over rate not picked up by another inlet requires some explanation of its disposal in the Remarks column (Column 30).

Column 11. The runoff from the subject watershed and any pertinent carry-over equals the total runoff, Q.

Column 12. The reciprocal of the cross slope, $1/S_x$ (m/m), is determined from the proposed roadway cross sections.

Column 13. The longitudinal gutter slope S (m/m) is determined from the proposed roadway profile.

Column 14. The depth of flow, y, is calculated in this column with Equation 10-1. The depth of flow is used for

- computation of ponded width for gutter flow
- determination of length required for total interception in curb opening inlets on-grade
- details of flow interception for grate inlets on-grade

Column 15. The ponded width (T) is the product of $1/S_x$ and y (Columns 12 and 14) and should not exceed the limits given in the design criteria. In the example problem, the maximum permissible ponded width is 3.6 meters for the section of Lone Star Blvd., and 4.5 meters for Texas Avenue. If the allowable ponded width is exceeded, the usual adjustment is to space the inlets closer together. This adjustment effectively removes the water from the surface at more frequent intervals and limits the accumulated discharge. On the other hand, if the width of ponding is significantly less than the allowable ponded width, you may find it economical to reduce the number of inlets in the system.

Column 16. The curb opening gutter depression (a) is expressed in meters (see Figure 10-14).

Column 17. The value of E is an exponent which is applicable to the calculation of total interception length for on-grade slotted drain inlets. See Equation 10-21.

Column 18. The value of W is the width of grate (meters) for an on-grade grate inlet or the depression width for an on-grade curb inlet.

Column 19. The value of L is the length of an on-grade grate inlet (meters). You, the designer, must select this value.

Column 20. The length of on-grade curb opening inlet that is required to intercept all of the flow (L_r) is determined through the following steps (see the following table).

On Grade Curb Inlet Calculations

a ID	b A_w m^2	c P_w m	d K_w	e A_o m^2	f P_o m	g K_o	h E_o	i S_e	j L_r m
A1	0.079	0.509	1.531	0.147	2.658	1.425	0.518	0.119	3.70
C1	0.071	0.508	1.284	0.152	3.115	1.346	0.488	0.104	4.18
E2	0.057	0.507	0.887	0.123	3.434	0.888	0.500	0.096	3.65
G1	0.064	0.508	1.071	0.109	2.644	0.870	0.552	0.114	3.40
H1	0.047	0.507	0.640	0.063	2.456	0.363	0.638	0.116	1.65

H2	0.058	0.507	0.904	0.127	3.495	0.931	0.493	0.095	3.40

Column 20a. This column identifies the inlet.

Column 20b. The area of the depressed portion of the gutter (A_W) is expressed in square meters and is calculated with Equation F-8:

$$A_W = W S_x \left(T - \frac{W}{2}\right) + \frac{1}{2} aW$$

Equation F-8

where: S_x = cross slope (m/m)
T = calculated ponded width (m)
W = depression width for an on-grade curb inlet (m)
a = curb opening depression width (m)

Column 20c. The wetted perimeter of the depressed portion of the gutter (P_W), in meters, is determined with Equation F-9. The top of the curb opening is ignored here:

$$P_W = \sqrt{\left(WS_x + a\right)^2 + W^2}$$

Equation F-9

Column 20d. The conveyance of the depressed gutter section (K_W) is calculated with A_W and P_W substituted into Equation 10-8.

Column 20e. The area of the gutter/road beyond the depression width (A_O) is expressed in square meters and is calculated with Equation F-10:

$$A_O = \frac{S_x}{2} (T - W)^2$$

Equation F-10

Column 20f. The wetted perimeter of the portion of the gutter beyond the depression (P_O), in meters, is determined with the following approximation (because S_x is usually small):

$$P_O = T - W$$

Equation F-11

Column 20g. The conveyance of the gutter section beyond the depression (K_O) is calculated with A_O and P_O inserted into Equation 10-8.

Column 20h. E_O, the ratio of depression flow to total flow, is calculated using Equation 10-7.

Column 20i. The equivalent cross slope (S_e) for a depressed curb-opening inlet is determined with Equation 10-9.

Column 20j. The length of the on-grade curb-opening inlet that is required to intercept all of the flow (L_r), given in meters, is found with Equation 10-9.

Column 21. The length of an on-grade slotted drain inlet necessary to intercept all of the flow L_r) is determined by use of Equation 10-20.

Column 22. The value in this column represents the actual length to be installed for either a curb opening inlet or a slotted drain inlet. This will ordinarily be a nominal (standard) length. If there is to be no carryover for an on-grade inlet, this value will be greater than the value in Column 20 or Column 21 (depending on the inlet type). If there is carryover for an on-grade inlet, the inlet will be shorter, and you should use the original required length (for total interception) to calculate the intercepted discharge rate.

Column 23. The ratio of L_a to L_r (Column 22 divided by either Column 20 or Column 21, whichever is applicable) is used to calculate the interception rate for the designed inlet. If the ratio is 1.00 or greater, the inlet will intercept all of the flow, and there will be no carryover.

Column 24. This column is the difference of Column 16 divided by Column 18, the ratio of gutter depression (a) to gutter depression width (w) to calculate the interception rate for the designed curb opening inlet. This ratio is not applicable in calculations for slotted drain inlets or grate inlets (on-grade).

Column 25. The carryover rate (C.O.) is computed directly for on-grade curbs using Equation 10-11 or for slots using Equation 10-22 Equation 10-8. This will be zero if the actual inlet length is greater than the required length. For a grate-on-grade, first determine the intercepted flow as discussed for Column 27, and subtract this value from the total discharge. Carryover flow should usually not exceed about 30 percent of the total discharge approaching the inlet.

Column 26. If there is carryover for the subject inlet, you must select and consider a destination in subsequent calculations. You must not ignore even small rates of carryover discharge. The designated destination must be the nearest inlet accessible by the carryover flow. In the case of the curb opening inlet at node A1, the designated destination is node C1.

Column 27. The flow intercepted at an on-grade curb or slot is the total discharge minus the carryover flow (Column 11–Column 25). The "On Grade Inlet Calculations" table represents calculations for grate-on-grade inlets. Place the results of Column h of the table in this column for grate-on-grade inlets. The on-grade grate inlet discharge interception procedure follows that of on-grade curbs and slots discussed previously through Column 19. The "On Grade Grate Calculations" table shows the remaining calculations required to determine the rate of interception.

On Grade Grate Calculations

a ID	b E_o	c v_o m/s	d v m/s	e R_f	f R_s	g E_f	h Q_i m^3/s	i C.O. m^3/s
K1	0.277	1.984	0.642	1.0	0.358	0.531	0.068	0.060
L1	0.338	1.984	0.553	1.0	0.421	0.608	0.043	0.027
L2	0.290	1.984	0.621	1.0	0.372	0.548	0.061	0.050
L3	0.292	1.984	0.619	1.0	0.373	0.550	0.060	0.049

Column 27a. The inlet is identified in this column.

Column 27b. The ratio of frontal flow to total gutter flow (E_O) is calculated with Equation 10-7 in the same manner as shown in the "Summary of Hydrologic Computations" table for on-grade curbs but using a = 0.

Column 27c. The splash-over velocity (v_O) is determined with the applicable equation in Equation 10-2. In this example, a parallel grate is used; thus:

$$v_O = 0.224 + 2.437L – 0.869L^2 + 0.192L^3$$

where L is the length of the grate (m).

Column 27d. The approach velocity in the gutter is found with Equation 10-25.

Column 27e. The ratio of the frontal flow intercepted to the total frontal flow (R_f) is equal to 1.0 if the splash-over velocity is greater than the approach velocity. Equation 10-23 is used to determine R_f if the splash-over velocity is less than the approach velocity.

Column 27f. The ratio of side flow intercepted to total side flow (R_S) is determined with Equation 10-27.

Column 27g. The efficiency of the grate (E_f) is based on Equation 10-28.

Column 27h. The interception rate of the inlet (Q_i) is calculated with Equation 10-29.

Column 27i. The carryover rate is the difference between the actual discharge and the interception rate.

Column 28. The remarks column is often used for

- explanations
- specific documentation
- qualifying statements
- special calculations or references

Calculation Explanation for Curb Opening Inlets in Sags

The following discussion refers to Tables F-11 and F-12 regarding the calculations for curb opening inlets

Curb Inlets on Sag Calculations

Curb Inlets on Sag													
1 ID	**2** Type	**3** Area ha	**4** Wtd C	**5** CA ha	**6** Actual t_c min	**7** Inlet Time min	**8** Intensity mm/hr	**9** Q m^3/s	**10** C.O. m^3/s	**11** Total Q m^3/s	**12** $1/S_x$	**13** T_{allow} m	**14** y_{allow}
J1	SCurb	0.64	0.68	0.44	8.8	10.0	147.93	0.180	0.063	0.242	32	4.50	0.14
M1	SCurb	0.33	0.85	0.28	4.2	10.0	147.93	0.115	0.049	0.165	32	3.60	0.11
N1	SCurb	0.41	0.85	0.35	7.0	10.0	147.93	0.143	0.000	0.143	32	3.60	0.11

Curb Inlets on Sag Calculations (part 2)

Curb Inlets on Sag (Continued)												
ID	15	16	17	18	19	20	21	22	23	24	25	26
	Left Side				Right Side				Inlet			
	Slope m/m	% Q %	y m	T m	Slope m/m	% Q %	y m	T m	a m	W m	h m	$L_{req'd}$ m
J1	0.0050	50	0.10	3.19	0.0050	50	0.10	3.19	0.08	0.5	0.216	1.03
M1	0.0050	50	0.09	2.76	0.0050	50	0.09	2.76	0.08	0.5	0.188	0.72
N1	0.0050	50	0.08	2.62	0.0050	50	0.08	2.62	0.08	0.5	0.188	0.51

Columns 1 through 12. These columns are determined in the same manner as on-grade inlets.

Column 13. The allowable ponded width is given in the specifications at the beginning of this example.

Column 14. The allowable ponded depth (yallow) is the lower of the curb height and the depth calculated by multiplying the allowable ponded width by S_x = (Column 13 / Column 12).

NOTE: You must consider the approach flow to sag inlets in the evaluation of ponded widths in the gutter. Since you must observe the allowable ponded width, it is necessary to estimate curb and gutter flow widths from each direction to the inlet.

Column 15. This column is used to show the gutter slope on the left side of the inlet.

Column 16. Estimate the percentage of the total discharge that will enter the inlet from the left side. In this example, the left side discharge is taken as one-half of the total discharge.

Column 17. The depth of flow (y) is calculated with Equation 10-1. This should be lower than the allowable ponded depth in Column 14, otherwise a flanker inlet will be needed.

Column 18. The ponded width on the left side of the gutter is equal to the depth of flow divided by S_x = (Column 17 / Column 12). If this value exceeds the allowable ponded width, a flanker inlet will be necessary on the left approach.

NOTE: Columns 19 through 22 are identical to Columns 15 through 18 except that they apply to the right side of the inlet.

Column 19. The inlet depression, a (m), is given in the specifications for this example.

Column 20. The lateral width of the inlet depression, W (m), is used in the calculation of the required inlet length.

Column 21. The allowable head on the inlet (h) is the sum of the allowable ponded depth (y_{allow}) and the inlet depression, a, (Column 14 + Column 23).

Column 22. The required length of the curb is computed using Equation 10-17. At this point, a standard size inlet would be chosen that meets or exceeds the required length.

NOTE: It is advisable to provide a safety factor of about 2:1. Use judgment relative to the anticipated type and quantity of debris that the inlet must accommodate.

Calculation Explanation for Grate Inlets

The following procedure refers to Tables F-13 and F-14. Instead of attempting to size a grate for this example, w e examine a standard size inlet to determine whether it will accommodate a given flow.

Grate Inlets on Sag Calculations

Grate Inlets on Sag										
1 **ID**	**2** **Type**	**3** **Area** **ha**	**4** **Wtd C**	**5** **CA** **ha**	**6** **Actual t_c** **min**	**7** **Inlet Time** **min**	**8** **Intensity** **mm/hr**	**9** **Q** **m^3/s**	**10** **C.O.** **m^3/s**	**11** **Total Q** **m^3/s**
A2	SGrate	0.06	0.70	0.04	2.0	10.0	147.93	0.017	0.000	0.017
A3	SGrate	0.10	0.70	0.07	2.0	10.0	147.93	0.029	0.000	0.029
A5	SGrate	0.05	0.70	0.04	2.0	10.0	147.93	0.014	0.000	0.014
A7	SGrate	0.04	0.70	0.03	2.0	10.0	147.93	0.012	0.000	0.012
A9	SGrate	0.12	0.70	0.08	3.4	10.0	147.93	0.035	0.000	0.035

Grate Inlets on Sag Calculations (part 2)

Grate Inlets on Sag (Continued)							
1 **ID**	**12** $\mathbf{h_{allow}}$ **m**	**13** **P** **m**	**14** $\mathbf{Q_w}$ $\mathbf{m^3/s}$	**15** **A** $\mathbf{m^2}$	**16** $\mathbf{Q_o}$ $\mathbf{m^3/s}$	**17** **Capacity** $\mathbf{m^3/s}$	**18** **Remarks**
A2	0.6	0.9	0.69	0.094	0.216	0.216	Orifice control, size OK
A3	0.6	0.9	0.69	0.094	0.216	0.216	Orifice control, size OK
A5	0.6	0.9	0.69	0.094	0.216	0.216	Orifice control, size OK
A7	0.6	0.9	0.69	0.094	0.216	0.216	Orifice control, size OK
A9	0.6	0.9	0.69	0.094	0.216	0.216	Orifice control, size OK

Columns 1 through 11. These columns are determined in the same manner as on-grade inlets.

Column 12. Since we use the grate inlets for this example in a median ditch area, gutter ponding computations are not applicable. Separate calculations (not shown here) must ensure adequate capacity of the median ditch. We give the allowable ponded depth (h_{allow}) in the example problem specifications. Since no depression is applied, the allowable ponded depth of 0.6 m will be the allowable head on the median inlets.

Column 13. The perimeter for a square inlet receiving flow from four sides is four times the side length minus the width of bars in the grate configuration (i.e., the available length for flow to enter the inlet). Assuming a reduction of 0.2 m for bars, the perimeter is 2–0.2 = 1.8 m. Considering the potential for clogging, assume 50% of this as a reasonable safety factor, giving an effective perimeter of 0.9 m.

Column 14. The capacity of a grate operating as a weir (Qw) is calculated with Equation 10-31.

Column 15. The area of the parallel bars in this example comprises about 25 % of the grate area. Thus, the clear opening area of the inlet will be 75 % of the total grate area giving 0.188 m^2. Considering the potential for clogging, reduce this by 50% to give an effective area of 0.094 m^2.

Column 16. The capacity of the inlet operating in orifice flow is computed with Equation 10-32.

Column 17. The capacity of the inlet is based on the minimum flow calculated in Columns 14 and 16. For all of the inlets, the capacity is larger than the total discharge, indicating that the grate sizes will suffice.

Conduit Design Explanation

Tables F-15 and F-16 show the suggested tabular format for calculations in the development of the conduit system, and this subsection describes the format.

Conduit Design Calculations

From ID	To ID	Area (hectares)	CA	Sum CA	External Time (min)	Accum. Time (min)	Time Used (min)	Intensity (mm/hr)	Discharge (m^3/s)
1	2	3	4	5	6	7	8	9	10
A1	A2	0.79	0.46	0.46	7.5		10.0	147.93	0.191
B1	A2	0.11	0.09	0.09	3.2		10.0	147.93	0.039
A2	A3	0.06	0.04	0.60	2.0	7.7	10.0	147.93	0.247
C1	A3	0.92	0.51	0.51	14.5		14.5	124.51	0.176
D1	A3	0.14	0.12	0.12	4.1		10.0	147.93	0.049
A3	A4	0.10	0.07	1.30	2.0	14.8	14.8	123.40	0.445
E1	E2	0.22	0.11	0.11	5.0		10.0	147.93	0.045
E2	A4	0.53	0.32	0.43	13.5	6.4	13.5	128.96	0.156
A4	A5	0.00	0.00	1.73		14.9	14.9	122.70	0.591
G1	A5	0.52	0.30	0.74	9.0	9.1	10.0	147.93	0.302
F1	A5	0.09	0.08	0.08	3.6		10.0	147.93	0.031
A5	A6	0.05	0.04	2.58	2.0	15.5	15.5	120.24	0.862
J1	G1	0.64	0.44	0.44	8.8		10.0	147.93	0.180
H1	H2	0.14	0.10	0.10	6.0		10.0	147.93	0.039
I1	H2	0.39	0.24	0.24	8.0		10.0	147.93	0.097
H2	A6	0.34	0.25	0.58	6.5	8.8	10.0	147.93	0.240
L1	L2	0.37	0.22	0.22	17.7		17.7	112.34	0.070
K1	L2	0.79	0.37	0.37	15.0		15.0	122.41	0.127
L2	L3	0.24	0.20	0.80	3.6	19.0	19.0	108.13	0.241
L3	A6	0.17	0.14	0.95	3.0	20.0	20.0	105.10	0.277
A6	A7	0.00	0.00	4.11		20.2	20.2	104.50	1.194
M1	A7	0.33	0.28	0.28	4.2		10.0	147.93	0.115
N1	A7	0.41	0.35	0.35	7.0		10.0	147.93	0.143
A7	A8	0.04	0.03	4.77	2.0	20.6	20.6	103.40	1.370
Off	A8	1.67	1.39	1.39	11.6		11.6	138.52	0.536
A8	A9	0.00	0.00	6.16		21.0	21.0	102.35	1.753
A9	A10	0.12	0.08	6.24	3.4	21.6	21.6	100.74	1.749

Conduit Design Calculations (part 2)

From ID	To ID	U/S Soffit Elev. (m)	D/S Soffit Elev. (m)	Conduit Length (m)	Slope (%)	RCP Size Required (mm)	Nominal Size (mm)	Uniform Depth (m)	Velocity (m/s)	Travel Time (min)	Time at end of Conduit (min)	Remarks
1	**2**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
A1	A2	256.760	256.670	20	0.450	436	450	0.341	1.48	0.2	7.7	
B1	A2	256.730	256.670	20	0.300	259	450	0.146	0.86	0.4	3.6	
A2	A3	256.670	256.200	100	0.470	477	600	0.315	1.65	1.0	8.7	CA = 0.46+0.09+0.04=0.60
C1	A3	256.260	256.200	20	0.300	457	600	0.294	1.28	0.3	14.8	
D1	A3	256.270	256.200	20	0.350	275	450	0.159	0.97	0.3	4.4	
A3	A4	256.200	256.090	20	0.550	577	600	0.446	1.98	0.2	14.9	CA = 0.60+0.51+0.12+0.07=1.30
E1	E2	256.600	256.150	90	0.500	249	450	0.139	1.08	1.4	6.4	
E2	A4	256.150	256.090	20	0.300	436	450	0.340	1.21	0.3	13.8	CA = 0.11+0.32=0.43
A4	A5	256.090	255.730	75	0.480	659	750	0.466	2.05	0.6	15.5	CA = 1.30+0.43+0.00=1.73
G1	A5	255.810	255.730	20	0.400	530	600	0.376	1.62	0.2	9.3	CA = 0.44+0.30=0.74
F1	A5	255.830	255.730	25	0.400	227	450	0.127	0.92	0.5	4.1	
A5	A6	255.730	255.490	75	0.320	819	900	0.596	1.93	0.6	16.2	CA = 1.73+0.74+0.08+0.04=2.58
J1	G1	255.940	255.810	25	0.520	415	450	0.306	1.56	0.3	9.1	
H1	H2	255.880	255.560	125	0.256	268	450	0.153	0.82	2.6	8.6	
I1	H2	255.810	255.560	60	0.417	343	450	0.221	1.24	0.8	8.8	
H2	A6	255.560	255.490	57	0.123	607	750	0.405	0.99	1.0	9.8	CA = 0.10+0.24+0.25=0.58
L1	L2	256.320	255.850	95	0.495	294	450	0.176	1.22	1.3	19.0	
K1	L2	256.070	255.850	55	0.400	383	450	0.265	1.31	0.7	15.7	
L2	L3	255.850	255.570	86	0.326	506	600	0.347	1.42	1.0	20.0	CA = 0.22+0.37+0.20=0.80
L3	A6	255.570	255.490	20	0.400	513	600	0.355	1.59	0.2	20.2	CA = 0.80+0.14=0.95
A6	A7	255.490	255.220	56	0.482	857	900	0.653	2.41	0.4	20.6	CA = 2.58+0.58+0.95+0.00=4.11
M1	A7	255.300	255.220	20	0.400	369	450	0.249	1.28	0.3	4.5	
N1	A7	255.240	255.220	18	0.111	509	600	0.351	0.83	0.4	7.4	
A7	A8	255.220	254.880	60	0.567	875	900	0.686	2.64	0.4	21.0	CA = 4.11+0.28+0.35+0.03=4.77
Off	A8										11.6	Inflow from external system
A8	A9	254.880	254.270	104	0.587	954	1050	0.693	2.89	0.6	21.6	CA = 4.77+1.40+0.00=6.17
A9	A10	254.270	254.030	40	0.600	949	1050	0.687	2.91	0.2	21.8	CA = 6.17+0.08=6.24

Column 1. This column identifies the upstream node of the subject run (segment). The identification code should correspond to the inlet/junction and associated watershed considered previously in the design process.

Column 2. This column identifies the downstream node of the subject run (segment). This identification code should correspond to the inlet/junction and associated watershed considered previously in the design process.

Column 3. This column contains the drainage area that is directly accommodated by the upstream inlet of the subject conduit. Water enters the conduit system for the first time from this watershed. Where there is no inlet at the upstream node (i.e., a manhole or junction), the watershed area is listed as 0.00 hectares.

This value is not used directly in the calculations for conduit design. However, the total accumulated watershed areas are ultimately needed for proper consideration of the tailwater conditions. Column 3 is a convenient place to tabulate the individual watersheds so that a total of all watershed areas can be made later.

Column 4. The value in this column is the product of the drainage area and weighted runoff coefficient that is directly accommodated by the upstream inlet of the subject conduit.

Column 5. The value in this column is a summation of the products of drainage area and associated runoff coefficients from all areas that contribute runoff to the upstream node. It is useful and convenient to show the summation calculation or the contributing nodes in Column 21 (Remarks).

Column 6. This column shows the external time of concentration from the individual drainage area that contributes flow directly to the inlet at the upstream end of the subject run. This will be carried over from Column 7 of the inlet calculations (Table F-5). Where there is no inlet at the upstream node, there can be no time of concentration in this column.

This value will be compared to other times of concentration in the search for the longest (effective) time of concentration which will serve as the basis for the rainfall intensity calculation.

Column 7. This column contains the longest time of concentration approaching the upstream node of the subject run from the conduit system upstream shown in Column 20. If the run is a lateral, there will be no upstream runs, and there will be no value for this column.

Column 8. The value of time of concentration shown in this column is the greatest of one of the following:

- time of concentration of surface flow to the inlet at the upstream node of the subject run (Column 6)
- longest time of concentration approaching the upstream node of the subject run from any incoming conduit at the upstream node (Column 7)
- minimum time of concentration to be used for derivation of rainfall intensity (In department practice, this value is taken as 10 minutes.)

The value shown in Column 8 is used to derive the rainfall intensity to calculate the discharge to be accommodated by the subject run.

Column 9. The rainfall intensity in this column is based on the value of the longest time of concentration (or minimum time of concentration) indicated in Column 8. Equation F-5 is used for this calculation.

Column 10. This column contains the total discharge to be accommodated by the subject run. This is done in accordance with Equation F-6 (i.e., 0.00278 × Column 9 × Column 5).

Column 11. The upstream soffit elevation of the location listed in Column 1 appears in this column.

Column 12. The soffit elevation of the downstream location (Column 2) appears here.

Column 13. This column shows the length of the run to be used for calculation of conduit slope and travel time (and ultimately, the friction loss for hydraulic grade line development).

Column 14. The value in this column is the conduit slope, calculated by dividing the difference in soffit elevations by the conduit length. The conduit slope is shown as a percentage for convenience, but design equations require the slope value be in terms of m/m.

Column 15. This column indicates the calculated required conduit size. For circular pipe, use Equation 10-40 (RCP).

Column 16. The design dimension for the subject run appears here. All calculations for the subject run which follow this choice will use this dimension as a basis. For non-pressure flow design, this value should be larger than the size determined in Column 15.

Column 17. The uniform depth in the pipe is shown in this column. For circular conduits, this value is determined by trial and error and is used in estimating the average velocity of flow in the conduit. See the Average Velocity subsection in Section 1 of Chapter 6.

Column 18. The average velocity of flow in the conduit is based on continuity (Equation 10-41), assuming that the average depth of flow is uniform depth.

Column 19. The travel time shown in this column is based on a division of run length by average velocity. Divide this value by 60 to determine the time in minutes.

Column 20. This column shows the sum of the operative (or real) time of concentration and the travel time within the subject run. The result represents the time of concentration at the downstream end of the subject run.

Column 21. You can use the remarks column for a variety of functions. The following may be recorded in this column as the design is developed:

- documentation and design notes
- additional information and
- clarification.

NOTE: You may configure the tabular calculation format in several different ways to accommodate necessary calculations.

Calculation Explanation for Hydraulic Grade Line

The storm drain system is being designed to accommodate a five-year frequency flood. Using Section 7 of Chapter 10, Hydraulic Grade Line Analysis, you must determine an appropriate beginning level at the outfall for development of the hydraulic grade line. The next subsections deal with the following:

- total watershed
- suggested downstream frequency
- hydraulic grade line development calculations

Total Watershed

The total watershed area served by the storm drain system is 9.18 hectares. The watershed for the outfall channel comprises 906.5 hectares. The ratio of these areas is about 100:1.

Suggested Downstream Frequency

With reference to Frequencies for Coincidental Occurrence , the suggested downstream (outfall channel) frequency for use in developing the hydraulic grade line is two years. The two-year water surface elevation in the outfall channel is 254.36. Since the soffit elevation of the node at A10 is 254.03, the hydraulic grade line should be developed throughout the system for this example.

Hydraulic Grade Line Development Calculations

The "Hydraulic Grade Line Calculations" table shows the suggested tabular format for calculations in the development of the hydraulic grade line in this example, and this subsection explains the columns.

Hydraulic Grade Line Calculations

D/S ID	U/S ID	Q (m^3/s)	Conduit Length (m)	Nominal Size (mm)	Friction Slope (%)	Conduit Slope (%)	Friction Loss (m)	D/S HGL (m)	D/S HGL + Loss (m)	Uniform Depth (m)	U/S FL Elev. (m)	U/S FL + Uniform Depth (m)	U/S HGL (m)	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A10	A9	1.749	40	1050	0.350	0.600	0.140	254.360	254.500	0.687	253.220	253.907	254.500	D/S HGL @ outfall elevation
A9	A8	1.753	104	1050	0.351	0.587	0.365	254.500	254.865	0.693	253.830	254.523	254.865	
A8	A7	1.370	60	900	0.489	0.567	0.293	254.865	255.159	0.686	254.320	255.006	255.159	
A7	N1	0.143	18	600	0.046	0.111	0.008	255.159	255.167	0.351	254.640	254.991	255.167	
A7	M1	0.115	20	450	0.140	0.400	0.028	255.167	255.195	0.249	254.850	255.099	255.195	
A7	A6	1.194	56	900	0.371	0.482	0.208	255.195	255.403	0.653	254.590	255.243	255.403	
A6	L3	0.277	20	600	0.173	0.400	0.035	255.403	255.437	0.355	254.970	255.325	255.437	
L3	L2	0.241	86	600	0.132	0.326	0.113	255.437	255.551	0.347	255.250	255.597	255.597	
L2	K1	0.127	55	450	0.170	0.400	0.094	255.597	255.691	0.265	255.620	255.885	255.885	
L2	L1	0.070	95	450	0.052	0.495	0.049	255.885	255.934	0.176	255.870	256.046	256.046	
A6	H2	0.240	57	750	0.040	0.123	0.023	256.046	256.069	0.405	254.810	255.215	256.069	
H2	I1	0.097	60	450	0.098	0.417	0.059	256.069	256.128	0.221	255.360	255.581	256.128	
H2	H1	0.039	125	450	0.016	0.256	0.020	256.128	256.148	0.153	255.430	255.583	256.48	
G1	J1	0.180	25	450	0.338	0.520	0.085	256.148	256.232	0.306	255.490	255.796	256.232	
A6	A5	0.862	75	900	0.193	0.320	0.145	256.232	256.377	0.596	254.830	255.426	256.377	
A5	F1	0.031	25	450	0.010	0.400	0.003	256.377	256.380	0.127	255.380	255.507	256.380	
A5	G1	0.302	20	600	0.207	0.400	0.041	256.380	256.421	0.376	255.210	255.586	256.421	
A5	A4	0.591	75	750	0.240	0.480	0.180	256.421	256.602	0.466	255.340	255.806	256.602	
A4	E2	0.156	20	450	0.255	0.300	0.051	256.602	256.653	0.340	255.700	256.040	256.653	
E2	E1	0.045	90	450	0.021	0.500	0.019	256.653	256.672	0.139	256.150	256.289	256.672	
A4	A3	0.445	20	600	0.449	0.550	0.090	256.672	256.762	0.446	255.600	256.046	256.762	
A3	D1	0.049	20	450	0.025	0.350	0.005	256.762	256.767	0.159	255.820	255.979	256.767	
A3	C1	0.176	20	600	0.070	0.300	0.014	256.767	256.781	0.294	255.660	255.954	256.781	
A3	A2	0.247	100	600	0.138	0.470	0.138	256.781	256.919	0.315	256.070	256.385	256.919	
A2	B1	0.039	20	450	0.016	0.300	0.003	256.919	256.922	0.146	256.280	256.426	256.922	
A2	A1	0.191	20	450	0.383	0.450	0.077	256.922	256.998	0.341	256.310	256.651	256.998	

Column 1. For convenience, the downstream node identification is given first. Because the storm drain system is a dendritic system, the one node may serve as the downstream location for multiple runs (except for the outfall).

Column 2. This column contains the upstream node identification.

Column 3. The discharge listed here is determined in the hydrologic development of the conduit system design.

Column 4. The length of the run is listed here and is influential in the hydraulic grade line development.

Column 5. This column repeats the diameter as assigned in the design of the conduit system.

Column 6. The friction slope, S_f, for the subject run is calculated according to Manning's Equation and rearranged as Equation 10-43. This value is shown as a percentage but must be expressed in m/m for calculations.

Column 7. The conduit slope as described in the design of the conduit system appears here, repeated for mathematical convenience.

Column 8. The friction loss in the run is the product of the friction slope (Column 6) and the run length (Column 4). This loss usually is the most significant.

Column 9. This column lists the hydraulic grade line elevation at the downstream node. The value shown here for the most downstream run is the level of the water surface in the outfall channel. This is because the water surface in the outfall channel (tailwater level), in this example, is greater than the soffit elevation of the downstream node of the most downstream run.

Column 10. The sum of the hydraulic grade line elevation at the downstream node of the subject run and the friction loss is a tentative estimate of the level of the hydraulic grade line at the upstream node in this tabular analysis.

Column 11. The uniform depth of flow is indicated in this column.

Column 12. This column indicates the flow line elevation for the upstream node. Usually, soffit elevations are matched when conduit depths change. Therefore, it is important to take this into account when calculating the flow line elevations throughout a conduit system.

Column 13. The sum of the upstream flow line elevation of the subject run and the uniform depth of flow is indicated here.

Column 14. This column shows the greater value of either Column 10 or Column 13. If the hydraulic grade line, as developed through summing friction losses, falls to a lower level of the soffit elevation in the conduit, calculations do not necessarily have to continue *if* the conduit system has been designed as a non-pressure flow system and other minor losses are expected to be negligible. Refer to Equation 10-47 and the Junction Loss Equation, Exit Loss Equation, and Manhole Loss Equations subsections in Chapter 10, Section 7 for accommodation of minor losses.

Column 15. You can use the remarks column for a variety of functions. As the design is developed, this column may include

- documentation and design notes
- additional information
- clarification
- self-reminders

Check all laterals for possible entrance control head in accordance with Section 4 of Chapter 8. The design is not complete until you have checked all nodes to ensure that the hydraulic grade line does not exceed any inlet throat elevations or manhole covers (critical elevations).

NOTE: The tabular calculation format may be configured in several different ways to account for necessary calculations. For example, you may need additional columns for calculating junction losses. We encourage you to devise a tabular calculation system that best accounts for personal style.